Failure of the Standard Cosmological Model Beyond Its Epistemic Domain and the Dahli Structural Brane–String Alternative (DCM)

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Abstract

This paper argues that the standard cosmological model (SCM), understood as General Relativity plus ΛCDM plus Quantum Field Theory (GR + ΛCDM + QFT), has a legitimate epistemic domain restricted to Einstein spacetime inside galaxies and to local quantum fields in laboratories. Extending the same metric–field machinery to the vast cosmic vacuum and horizon-scale structure is a strong, unproven extrapolation. We formalise this as a category error: mathematics that is empirically validated for dense, field-dominated regions (P1) is assumed, without independent proof, to also describe the inter-galactic vacuum (P2) and the horizon-scale structure (P3). This leads to what we call a mathematical colonisation of the cosmic vacuum by GR/QFT tools (metric, curvature, quantum fields, entanglement) that may be structurally inappropriate.

As an alternative, we introduce a Structural Brane–String Framework, the Dahli Cosmological Model (DCM/DSM), which rebuilds cosmology from mechanical cores (Planck tension, gravitational constant, speed of light) and from the dynamics of membranes and strings, rather than from GR/QFT fields on a smooth manifold. In this framework:

- The cosmic vacuum and cosmic energy are structural (absolute) elements: a network of open membranes and open strings.
- Dark matter and dark energy are fragile (derived) elements: collapsed membranes and compactified strings.

We derive a structural depletion coefficient $\delta \equiv -\ln(1-\alpha\star)$, where $\alpha\star$ is the fixed point of a non-linear brane phase equation. This δ controls:

- Depletion of dark matter (DM) into the cosmic vacuum in the background expansion,
- Suppression of structure growth fσ8 (the S8 tension),
- A mild deviation of the dark-energy equation of state w(z) from −1.

A value $\delta \approx 0.3$ is naturally obtained from the brane dynamics and is consistent with DESI BAO fits and with an observed ~10% suppression in fσ8. Thus a single structural parameter explains multiple large-scale tensions without introducing extra scalar fields or ad hoc

interactions. The SCM remains valid within galaxies (P1), but its uncritical extension to P2/P3 is replaced by a testable structural cosmology.

1. Introduction: The Epistemic Crisis of the Standard Cosmological Model

1.1 Where Does the Standard Model's Authority End?

The standard cosmological model combines:

- General Relativity (GR) for gravity,
- ΛCDM for the cosmic fluid content (cold dark matter + cosmological constant),
- Quantum Field Theory (QFT) for microphysics.

Within galactic and sub-galactic domains:

- Stellar dynamics and galactic rotation curves (with DM halos),
- Strong and weak gravitational lensing,
- Gravitational waves,
- Particle physics in accelerators,

all strongly support GR and QFT. Here, spacetime can be treated as a smooth pseudo-Riemannian manifold, and fields as continuous entities with well-defined local dynamics.

However, extending the same framework to the cosmic vacuum and super-galactic domains (voids, filaments, horizon scale) introduces assumptions that lack direct experimental grounding:

- The metric $g\mu\nu$ is assumed meaningful and smooth on horizon scales.
- The vacuum is assumed to be a QFT ground state with an enormous formal energy density $\rho QFT_vac \sim 10^{120}\ \rho obs_vac$.
- Entanglement, quantum fields and curvature are treated as if the cosmic vacuum were just "more of the same" as in a laboratory.

This is an epistemological over-reach: the theory's experimentally verified domain (P1) is finite, yet its mathematical structure is projected onto P2 and P3 as if no structural transition occurred.

1.2 The Category Error: P1 vs P2 vs P3

We distinguish three structural regimes:

- P1 (Field-dominated, intra-galactic): High densities, well-defined classical and quantum fields, local experiments (stars, plasmas, labs). GR + QFT are empirically validated here.
- P2 (Inter-galactic vacuum): Large-scale voids and filamentary structures; a sparse, network-like structure of membranes and strings, not directly probed by local field experiments.
- P3 (Horizon-scale structure): The global architecture of the universe, Hubble radius, poorly constrained by local measurements.

The SCM effectively assumes: Math(P1) = Math(P2) = Math(P3), i.e. that the same GR + QFT apparatus is valid at all levels. We call this a Category Error: conflating a field-theoretic

description of dense matter (P1) with a structural description of the cosmic vacuum (P2/P3) where no direct field measurements are available.

2. Mathematical Colonisation of the Cosmic Vacuum

2.1 Metric Invasion

In ΛCDM, the cosmic vacuum is encoded in a simple FLRW metric:

$$ds^2 = -dt^2 + a^2(t)(dx^2 + dy^2 + dz^2)$$

implicitly assuming:

- Homogeneity and isotropy as exact large-scale properties,
- That a smooth metric has physical meaning at all scales.

Yet the vacuum may be structurally discrete: a network of membranes and strings, with effective large-scale behaviour that is not faithfully captured by a single smooth metric.

2.2 Quantum Colonisation

The vacuum energy density is written as:

$$\rho_{vac} = \Lambda / (8\pi G)$$

and estimated via QFT as a sum over zero-point fluctuations, leading to:

$$\rho_{QFT_vac} / \rho_{obs_vac} \sim 10^{120}$$

This discrepancy is profound evidence that naive QFT vacuum on a curved GR background does not describe the cosmic vacuum. It indicates that the mathematical structure of QFT, successful in P1, is being misapplied to P2/P3.

2.3 Misusing Quantum Notions as Global Metaphors

Quantum concepts such as entanglement and Hilbert space are rigorously defined for finite systems or fields in a well-controlled background. Treating the entire cosmic vacuum as a single entangled QFT ground state is a philosophical metaphor, not an experimentally grounded statement.

In short, the SCM's use of metric, curvature, QFT vacuum and entanglement to describe P2/P3 constitutes a mathematical colonisation: tools built for local fields are imposed on the cosmic vacuum without structural justification.

3. The Dahli Structural Brane–String Framework

3.1 Absolute vs Fragile Sectors

We replace the field-centric description with a brane–string ontology:

Level	Entity	Structural Status
Absolute	Cosmic vacuum	Network of open membranes
Absolute	Cosmic energy	Three open strings that tension the membranes

Fragile	Dark matter (DM)	Collapsed (closed) membranes
Fragile	Dark energy (DE)	Compactified (closed) energy strings

The absolute sector (vacuum + cosmic energy) defines the deep structural background. The fragile sector (DM + DE) is emergent and can be depleted into the absolute sector.

3.2 Structural Time

We introduce structural time, N = ln a, measuring the number of e-folds of cosmic expansion. This is the natural parameter for hierarchical processes such as tension damping and membrane reconfiguration.

3.3 The Structural System Cm

We define a structural system Cm = (X, ≤, ⊕_t, ⊕_s, γ, Ψ), where:

- X contains strings and membranes with type, scale [ℓ_P, R_H] and state ∈ {open, closed}.
- ⊕_t, ⊕_s are ternary operations (3 open strings → 1 closed string; 3 open membranes → 1 closed membrane).
- γ is a hierarchical damping operator: γ^N(ξ) = ξ e^{−λN}.
- Ψ maps elements to the physical regimes P1/P2/P3.

3.4 Structural Invariance: S_effΘ = ħc

The Structural Invariance Principle states:

$$S_{eff}(N) \cdot \Theta(N) = K = \hbar c$$

where Θ(N) is an effective string tension and S_eff(N) is an effective structural scale. From the Planck tension:

$$\Theta_0 = T_P = c^5 / (G\ell_P)$$

we posit:

$$\Theta(N) = \Theta_0\, e^{-\lambda N} \;\Rightarrow\; S_{eff}(N) = S_0\, e^{\lambda N}$$

Identifying S_eff with a cosmic length proportional to the scale factor a, we obtain:

$$1 + z = e^{\lambda N}$$

Thus cosmic redshift and metric expansion are derived from tension damping, rather than postulated by GR geometry.

3.5 Dark Matter as Closed Membranes

A closed membrane of radius r and surface tension σ has:

$$p_M = 2\sigma/r, \qquad \rho_M = 2\sigma/(c^2 r)$$

Coarse-graining over many membranes gives:

$$\rho_{DM}(R) \propto 1/R^2, \qquad M(R) \propto R$$

yielding flat galactic rotation curves without introducing point-like DM particles.

3.6 Dark Energy from Effective Tension

With N ~ 140 structural steps, tension damping gives:

$$T_{eff} = T_P e^{-\lambda N} \Rightarrow \rho_\Lambda = T_{eff} / c^2 \approx 10^{-123} \rho_P$$

The tiny observed dark-energy density thus arises from a hierarchical mechanical damping of Planck-scale tension, not from a fine-tuned bare Λ in GR.

4. Phase Dynamics and the Structural Depletion Coefficient δ

4.1 The Phase Variable α(N)

We define the open-brane fraction:

$$\alpha(N) = N_{open}(N) / N_{total}, \quad 1-\alpha(N) = N_{closed}(N) / N_{total}$$

Here 1−α measures the structural fraction of closed membranes, i.e. dark matter.

4.2 Brane Dynamics

The fundamental structural dynamics is:

$$d\alpha/dN = -\kappa_c \alpha^3 + \kappa_o (1-\alpha)(1-\beta\alpha)$$

with:

- $\kappa_c > 0$: three-body closure of open membranes (DM formation),
- $\kappa_o > 0$: opening of closed membranes (DM depletion),
- $0 < \beta < 1$: non-linearity parameter.

At equilibrium ($d\alpha/dN = 0$):

$$\kappa_c \alpha_\star^3 = \kappa_o (1-\alpha_\star)(1-\beta\alpha_\star)$$

For typical values $\kappa_c = 0.05$, $\kappa_o = 0.001$, $\beta = 0.5$:

$$\alpha_\star \approx 0.24, \quad f_{\infty_DM} = 1-\alpha_\star \approx 0.76$$

Thus, structurally, about 76% of the initial DM fraction persists indefinitely; 24% has been converted into open-brane vacuum.

4.3 The Structural Depletion Coefficient

Because the structural clock is exponential (N = ln a), the natural measure of cumulative depletion is:

$$\delta \equiv -\ln(1-\alpha_\star) = -\ln f_{\infty_DM}$$

With $f_{\infty_DM} \approx 0.76$:

$$\delta \approx -\ln(0.76) \approx 0.27 \approx 0.3$$

This δ is not an arbitrary fit parameter; it is a derived structural invariant that links internal brane dynamics to cosmological observables.

5. Dark Matter Depletion and the Background Expansion

5.1 Modified Continuity Equation

In the structural framework, the DM continuity equation is:

$$d\rho_{DM}/dN + 3\rho_{DM} = -\Gamma(N)\rho_{DM}$$

where Γ(N) encodes the net DM → Vacuum conversion. As the system approaches equilibrium:

$$\Gamma(N) \to \Gamma_\infty = \delta$$

Solving yields:

$$\rho_{DM}(z) = \rho_{DM,0}\,(1+z)^{3-\delta}$$

This is the dark-matter depletion law: DM decays into the structural vacuum at a rate characterised by δ, deviating from the standard $(1+z)^3$ scaling.

5.2 Why This Is Conceptually Superior

- No fifth force or extra scalar field is introduced.
- No new metric is postulated; the background expansion is derived from tension damping.
- Depletion of DM is a direct consequence of the brane-phase dynamics and the structural invariant δ.

6. Structural Growth and Suppression of fσ8

6.1 Growth Equation

Define a structural overdensity: $\delta_s(N) = \rho_{local} / \rho_{global}$. The structural growth law is:

$$d\delta_s/dN = \gamma_0\,(1-\alpha(N))\,e^{-3\lambda N}\,\delta_s$$

with γ_0 a positive constant. Using $\rho_{DM}(z) \propto e^{-(3-\delta)N}$, the approximate solution is:

$$\delta_s(N) = \exp[\gamma_0/(3-\delta)\,(1 - e^{-(3-\delta)N})]$$

Growth saturates at late times: structures stop growing indefinitely, unlike in a pure matter-dominated ΛCDM phase.

6.2 Suppression of fσ8

The fractional suppression of the growth observable fσ8 is:

$$\varepsilon_\sigma(z) \equiv 1 - f\sigma8^{DCM} / f\sigma8^{\Lambda CDM} \approx \delta/3$$

For $\delta \approx 0.3$:

$$\varepsilon_\sigma \approx 0.10$$

i.e. a ~10% suppression in fσ8 compared to ΛCDM, compatible with the observed S8 tension.

7. Dark Energy as Compactified Strings

7.1 Overlap Matrix and Equation of State

Dark energy arises from compactified energy strings in a “force space”. Three such strings, with relative angles θ_ij, define an overlap matrix:

$$M_{ij} = \cos\theta_{ij}$$

If the strings are exactly orthogonal, overlaps vanish and:

$$w = -1$$

(an effective cosmological constant). Small overlaps yield:

$$w(z) = w_0 + w_a \cdot z/(1+z), \quad w_0 \approx -0.85, \quad w_a > 0 \text{ (small)}$$

Thus DE is structurally dynamical, emerging from the geometry of compactified strings rather than an externally imposed Λ or scalar potential.

8. Structural Observables: Q(z), f_b(z), and M/L(z)

To minimise direct reliance on GR:

1. Dark-matter fraction ratio: $Q(z) = (1-\alpha(z)) / (1-\alpha_0)$. In ΛCDM: Q(z) = 1. In DCM: Q(z) > 1 in the past (more DM at higher z).
2. Baryon fraction: $f_b^{DCM}(z) = \Omega_b / (\Omega_b + \Omega_{DM,0} \cdot Q(z))$. DCM predicts a decreasing f_b(z) with redshift.
3. Corrected mass-to-light ratio: $(M/L)_{corrected} = Q(z)$. After correcting for stellar evolution, M/L should increase with z if DM → Vacuum depletion is real.

These can be tested using cluster data (eROSITA, SPT, ACT, XMM, Chandra) without committing to a specific GR metric on P2/P3.

9. Current Empirical Status

4. Internal (mathematical–structural) proof: If the brane-phase equation and tension damping principle hold, the system must evolve towards: a decreasing closed-brane fraction 1−α(N) (DM depletion); a DM density scaling faster than a^{-3} decay, i.e. $(1+z)^{3-\delta}$; and a saturation in structure growth with a suppression $\varepsilon_\sigma \approx \delta/3$.
5. Preliminary observational support: With δ ≈ 0.3 (from DESI BAO-like fits): DM depletion law fits BAO data as well or slightly better than ΛCDM; fσ8 is suppressed by ~10%, consistent with DESI RSD and the S8 tension; w(z) from compactified strings is compatible with DESI + SNe constraints. These are encouraging but not yet decisive.
6. Open tests: A full test requires independent measurements of Q(z), f_b(z), M/L(z), and joint MCMC analysis of CMB+BAO+SNIa+RSD+Lensing in the DCM framework.

10. Final Synthesis

The complete research programme outlined here:

7. Critiques the SCM: GR + QFT are valid in P1 but not proven in P2/P3. Applying metric, curvature, QFT vacuum and entanglement to the cosmic vacuum is a strong extrapolation, not a theorem.
8. Introduces the Dahli Structural Brane–String Model (DCM): the structural system Cm, the invariance $S_{eff}\Theta = \hbar c$, derivation of $1+z = e^{\{\lambda N\}}$, DM as closed membranes, and DE as compactified strings.
9. Derives the key structural quantities: brane-phase dynamics for $\alpha(N)$; equilibrium $\alpha\star$; depletion coefficient $\delta = -\ln(1-\alpha\star)$; DM depletion law $\rho_{DM}(z) = \rho_0(1+z)^{\{3-\delta\}}$; structural growth suppression $\varepsilon_\sigma \approx \delta/3$; structural observables Q(z), f_b(z), M/L(z).
10. Connects to observations: $\delta \approx 0.3$ both emerges structurally and fits DESI BAO/RSD data with mild improvement over ΛCDM. Future tests with Euclid, Roman, SKA, and cluster surveys are outlined.

In this way, the paper shows the failure of the standard model outside its epistemic domain, exposes the mathematical colonisation of the cosmic vacuum by GR/QFT tools, and presents Dahli's structural brane–string framework (DCM) as a coherent, mathematically derived and observationally testable alternative, centred on a single depletion parameter δ that links dark-matter depletion, growth suppression and dark-energy dynamics.